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SEMI ANNUAL REPORT
(1 November 1963 - 30 April 1964)

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THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION
Columbus, Ohio

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NOTICES

REPORT
by
THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS 12, OHIO

Sponsor	National Aeronautics & Space Administration 1520 H Street, N. W. Washington 25, D. C.
Grant Number	NsG-213-61
Investigation of	Theoretical and Experimental Analysis of the Electromagnetic Scattering and Radiative Properties of Terrain, with Emphasis on Lunar-Like Surfaces
Subject of Report	Semi Annual Report (1 November 1963 - 30 April 1964)
Submitted by	Antenna Laboratory Department of Electrical Engineering
Date	1 May 1964

ABSTRACT

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This report reviews work aimed at clarifying the relations between the electromagnetic scattering properties of a surface (in particular the lunar surface) and its surface sturcture, carried out under National Aeronautics and Space Administration Grant Number NsG-213-61. Theoretical studies have been made of the correlation properties of the scattered signal as a function of frequency separation and surface roughness for the adjacent frequency scattering experiments. A laboratory model of the two-frequency system has been constructed to measure the correlation properties of the scattered signals from simple targets. A 10 kilowatt transmitter facility operating at a frequency of 2270 Mcs has been completed and is now in operation. The transmitter facility and the Ohio State University "Saucer Field" are now being used to measure the scattering properties of the lunar surface by the doppler technique.

author

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SEMI ANNUAL REPORT

I. INTRODUCTION

This report summarizes the work carried out during the past six-months on studies of the relations between the radar scattering properties of moon-like surfaces, including the lunar surface and their surface features. The significance of such a study for lunar and planetary research has been outlined in previous progress reports [1,2,3]. Briefly, with the more sophisticated lunar and planetary experiments under development it is important to understand the scattering behavior of the lunar surface in order to properly interpret the results of such experiments with regard to the physical characteristics of the surface. At the present time, information about the scattering behavior of the lunar surface is not available and, in fact, very little data can be found about the scattering behavior of any surface in relation to the physical characteristics. The lunar surface may provide a convenient place to test many of the ideas and techniques that can be useful in radar astronomy studies of other members of our solar system. Three areas of study have been pursued in order to provide the fundamental data needed, but which are not available at this time, to interpret or design lunar and planetary radar experiments and obtain immediate information about the structure of the lunar surface. These areas are (1) theoretical studies of the scattering from rough surfaces, with emphasis on the polarization transformation properties of the surface and the frequency dependence of the scattering; (2) measurements of the complete scattering properties of a number of "moon like" surfaces on the model range; and (3) measurement of the actual scattering properties of the moon by the doppler technique. Each of the above topics will be discussed in greater detail in the following sections.

II. THEORETICAL STUDIES

The principal effort during the past six months has been directed toward completing the analysis of the two-frequency radar experiment. For a flat surface with Gaussian statistics, the correlation between the returns is preportional to exp $[-\gamma^2\sigma^2(\Delta K)^2/2]$, where γ is related to the angle of incidence, σ is the r. m. s. surface roughness, and ΔK is the difference in wave number, i. e., $\Delta K = 2\pi\Delta f/c$ where Δf is the frequency difference and c the velocity of light. The amount of surface roughness required to reduce the correlation by a factor 1/e is plotted in Fig. 1, as a function of frequency separation. It is clear that a much larger range of surface roughness scales can be investigated by this method than by observing at a single frequency. This method has the further advantage or using two high frequencies, where problems of antenna design and propagation effects are much simpler than at the much lower frequencies that would be required to investigate the same class of surface irregularities by conventional techniques.

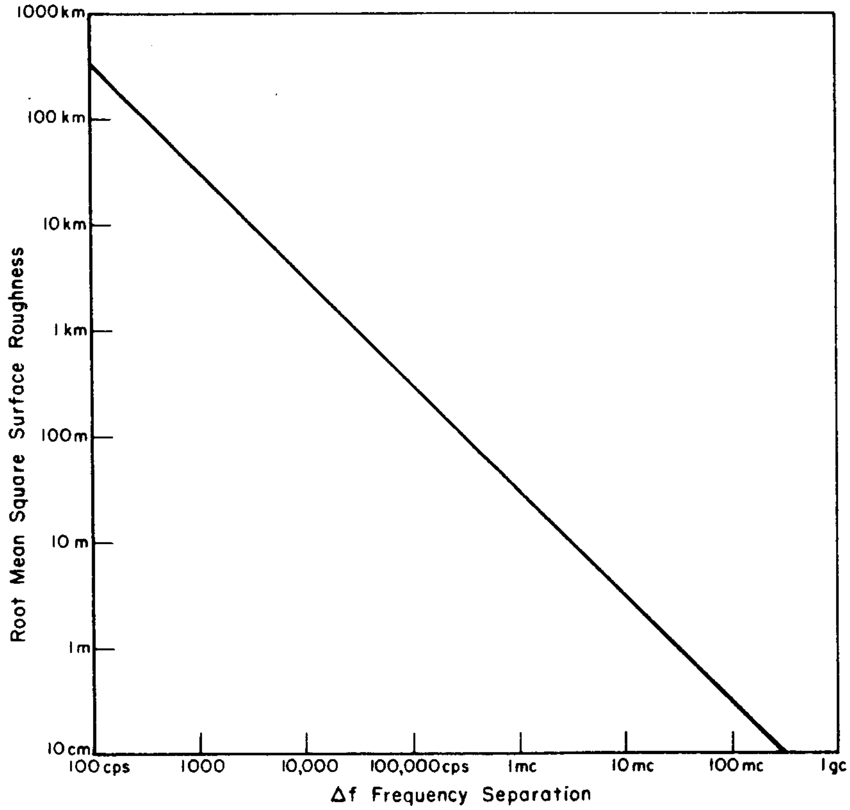


Fig. 1. Mean square-surface roughness vs. frequency separation for correlation equal to e^{-1}.

III. LUNAR RADAR EXPERIMENT

A. General Description of Experiment

The measurement of the lunar scattering properties by the doppler technique, utilizing the Ohio State University "Saucer Field" and the recently completed 10 Kw transmitter facility, has been described in part in Ref. 3. The experiment is concerned with measuring the scattering properties of the moon with an unmodulated cw radar. Because of the motion of the moon relative to the Earth, the reflected signal is shifted in frequency from the incident signal: first, because of the apparent rotation of the moon, as viewed from the Earth, an incident wave of one frequency results in the reflected energy spread out over a band of frequencies; and second, the apparent velocity of the center of the moon, as seen from the Earth, results in an overall doppler shift in frequency. The overall doppler shift is not of primary interest; only the doppler spread will be considered. Under certain conditions the doppler spread caused by the moon's apparent rotation can reach a maximum of approximately 30 cycles with a transmitted frequency of 2270 mc. The received signal from the "Saucer Field" is recorded on magnetic tape and then played back thru a power spectral density computer which has a resolution of 2 cycles. Thus, with a resolution of 2 cycles and a doppler spread of 30 cycles, it is possible to obtain the reflection coefficient from 15 different strips of the moon's surface.

B. Transmitter Facility

The transmitter located at Ohio University in Athens, Ohio[3], has been completed and is now in full operation. Since the resolution obtained on the moon's surface using the doppler technique is dependent upon the frequency stability of the transmitter, considerable effort has been expended in accurately controlling the frequency of the transmitter. A block diagram of the transmitter with the frequency control system is shown in Fig. 2. The reference frequency is obtained from a Sulzer crystal standard which has an accuracy of approximately 1 part in 10^{10}. The reference frequency, 5 mc, is multiplied and mixed with itself to provide both an RF reference, 230 mc, for the klystron stabilizer and an IF reference, 30 mc, for the phase detector in the stabilizer. The same reference frequency and techniques are used in the frequency monitor system to measure variations in the transmitter frequency. Frequency stability measurements have indicated the transmitter frequency variations on a per-second basis are less then 0.2 cycle; on a long-term basis (30 minutes) the variations are less than 5 cycles. A small probe installed on the surface of

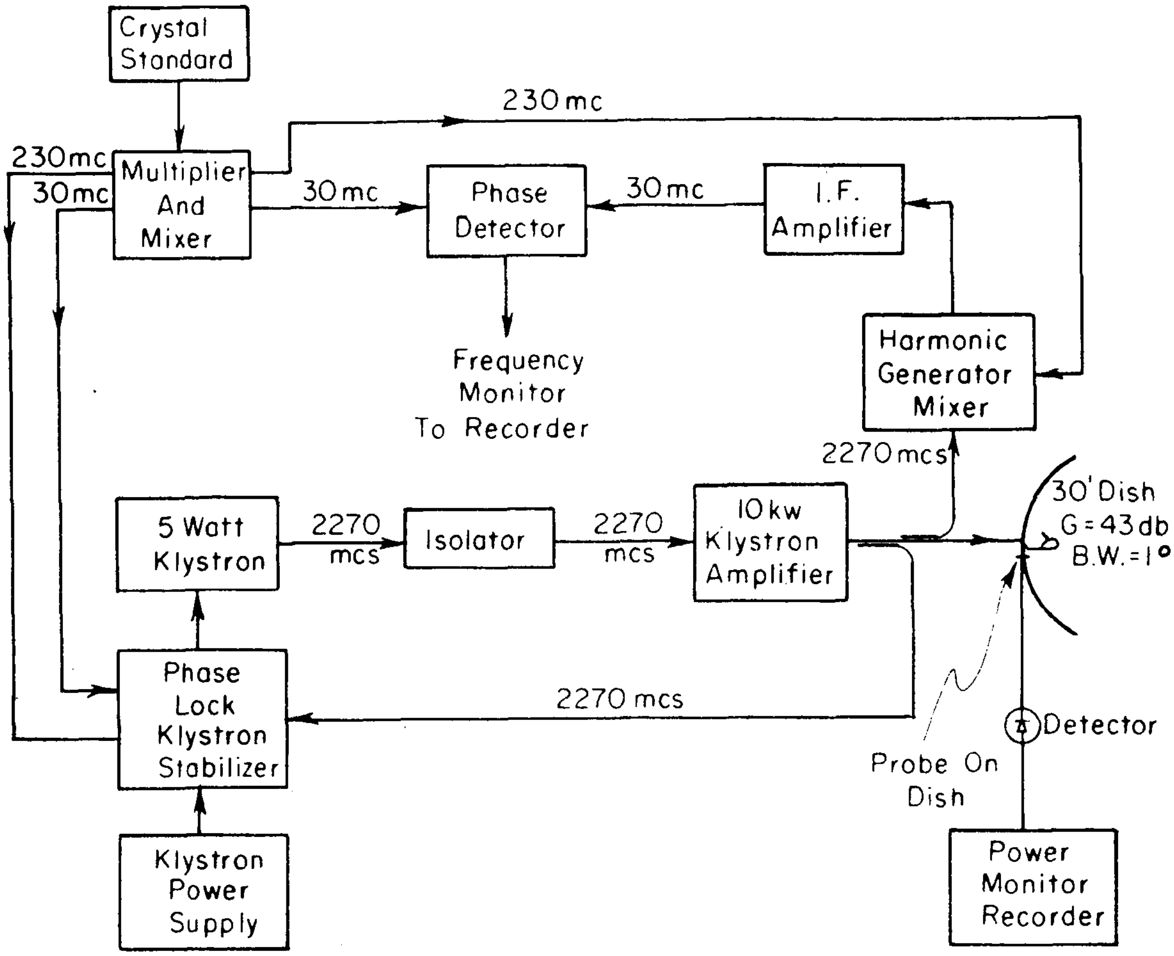
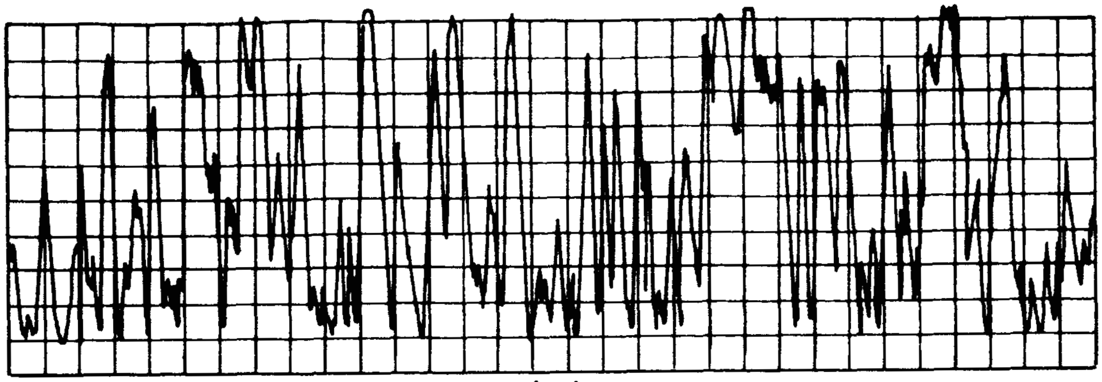


Fig. 2. 10 Kw Transmitter and frequency control system.

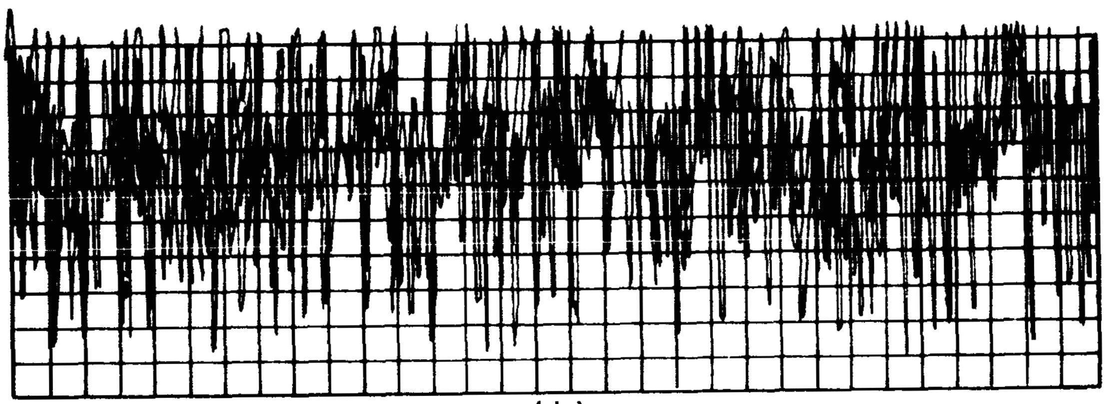
the parabolic reflector is used to measure variations in power, thus giving a true indication of the radiated power including variations in feed line loss as well as transmitter power. Power stability measurements have indicated that the variations in radiated power are less than ± 0.25 db.

Preliminary scattering measurements from the moon have been made to check the performance of the transmitter and receiving systems. Some preliminary results indicating the difference in fading rates for two different liberation rates of the moon are shown in Fig. 3. No attempt should be made to analyze these data on an absolute amplitude basis, since the primary data and calibration are recorded on magnetic tape. The preliminary measurements indicate a signal-to-noise ratio of approximately 21 db. An intensive measurement program for the power spectural density analysis will be started in the near future.



(a)

Fig. 3a. Preliminary scatterin measurements from the moon April 15 (First quarter).



(b)

Fig. 3b. Preliminary scattering measurements from the moon May 5 (Last quarter).

IV. SURFACE SCATTERING MEASUREMENTS

A. Bistatic Measurements

A number of moon-like surfaces have been constructed and their bistatic cross-sections measured using circular polarization. The results of the first phase of the bistatic scattering measurements are contained in Ref. 3. The results of the bistatic scattering measurements from the other phases of the experimental program will be presented in a forthcoming technical report. The bistatic scattering facility is located outdoors and the period of measurements has been limited to the summer months when the artifical surfaces have a minimum moisture content. Both bistatic and backscattering measurements of a number of moon-like surfaces will be continued, with emphasis on the polarization transformation properties of the surface.

B. Adjacent Frequency Experiment

The adjacent frequency technique, discussed in Section II and in Ref. 3, offers considerable promise for determining surface structure. An experimantal system for laboratory use has been constructed to operate at a frequency of 10 Kmc. A block diagram of the system is shown in Fig. 4. A target that is large with respect to the beamwidths of the antennas is continuously moved in front of the antennas by means of a motor-driven stick shaker. This creates the effect of looking at many independent samples of the targets surface structure. The preliminary measurements have been obtained using simple metallic targets with only one degree of surface roughness. Shown in Fig. 5 are the results from a metallic target with the surface roughness shown in Fig. 6. The frequency separation was 600 mc centered about a frequency of 10 Kmc. It can be seen from Fig. 4 that almost 100 per cent correlation has been obtained between the two received signals. Additional measurements are being obtained for more complex targets and a wide range of frequency separation.

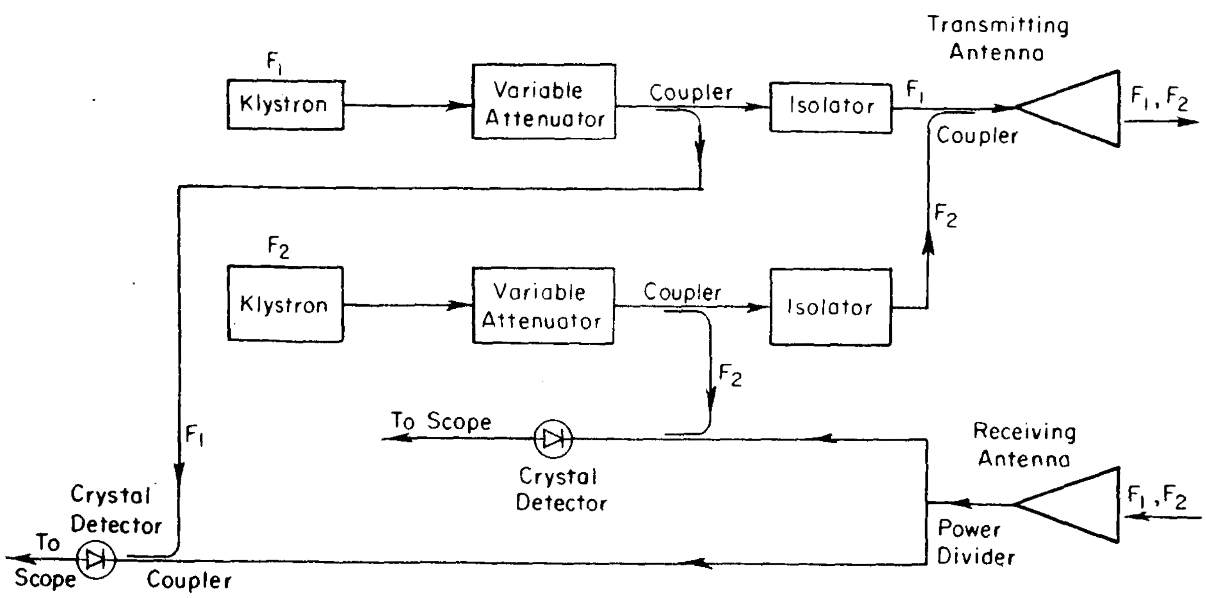


Fig. 4. Adjacent frequency system.

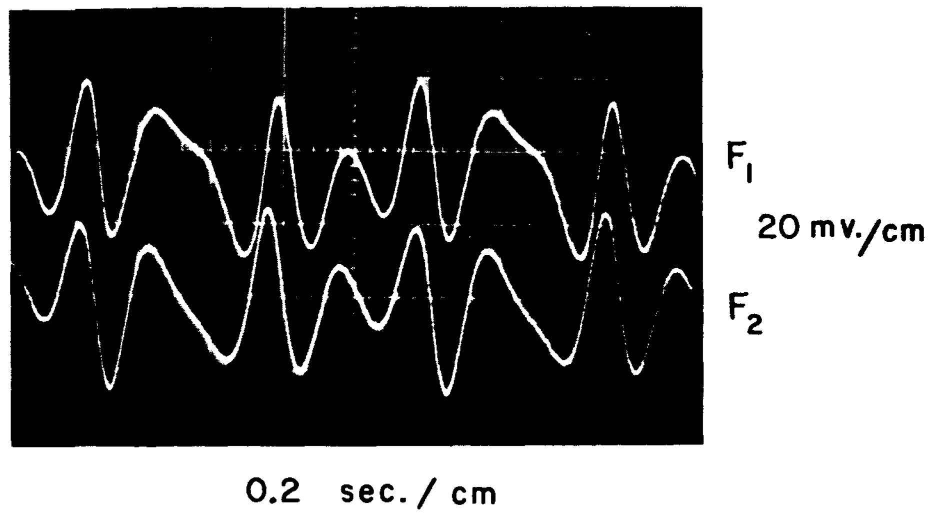


Fig. 5. Correlation of adjacent frequency measurements.

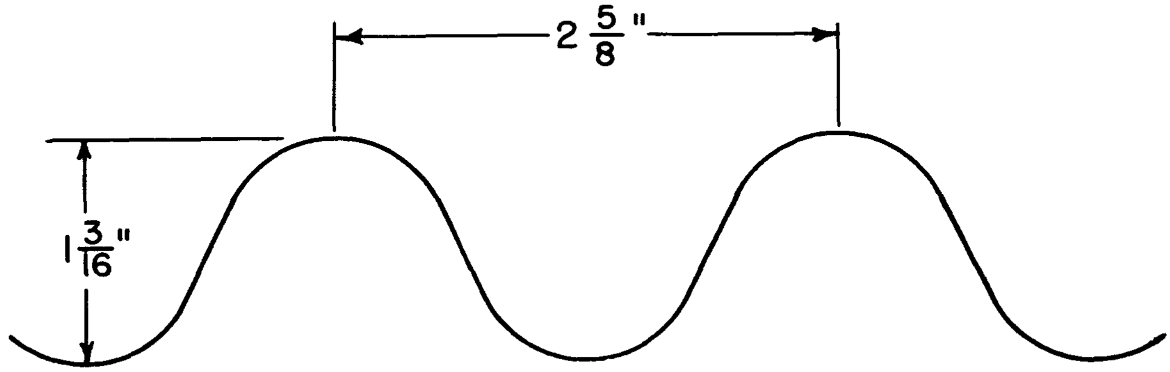


Fig. 6. Surface structure of simple metallic target.

V. PROPOSED WORK PROGRAM FOR THE REMAINDER OF THE GRANT PERIOD

For the remainder of the present grant period, our efforts will be directed toward continuing the three phases of work presently being pursued, especially since experimental data is just starting to be obtained from the lunar radar and adjacent frequency experiments. It is expected that a considerable amount of time will be spent in organizing and reducing the data obtained from the lunar radar experiment in order that it can be fully exploited.

Additional theorectical studies concerning the polarization transforming properties of rough surfaces will be made in order to properly interpret the results of the surface scattering measurements involving the "moon-like" surfaces. The theoretical studies involving the relationships between surface structure and the results of the adjacent frequency scattering will be continued. It is hoped that a clear understanding of these relationships can be established for the simple targets presently being measured.

The surface scattering studies will be continued and will include the measurement of a wider variety of surfaces. The results of these measurements will be compared to those obtained from the lunar radar experiment.

VI. PROPOSED WORK FOR COMING YEAR (NOVEMBER 1964 - OCTOBER 1965)

For the forthcoming year, in order to continue the program of studies on the radiating properties of the lunar and planetary surfaces, the following course of work is proposed:

A. Lunar Radar Experiments

The measurements of the scattering properties of the moon by the doppler spectrum technique, utilizing The Ohio State University "Saucer Field" and the recently completed 10 KW transmitter facility, will be continued. Considerable effort will be required on data analysis, and interpretation of the data just starting to be obtained from this experiment. The results of this experiment will be compared to those obtained from the "lunar like" surface studies and will also provide a check of the doppler method against the known pulse method for determining lunar and planetary scattering diagrams.

Preliminary results from the "adjacent frequency" experiment, in which the experimental parameter is the correlation between the scattered power from the surface as measured at two nearly equal frequencies, have shown considerable promise for simple targets. It is planned to incorporate this technique into the lunar radar experiment to investigate the lunar roughness structure for a variety of roughness/frequency-separation ratios.

B. Theoretical Studies

Theoretical studies would be continued in two directions. First is the interpretation of the results of the lunar radar experiments involving the doppler spectrum technique. Although the general problems involving the interpretation of the doppler spectrum have been studied in some detail, the large amount of data that can be obtained under such a program cannot be fully exploited unless it is organized and properly analyzed.

The studies involving the relationships between the "adjacent frequency" scattering and surface structure have just started and should be continued, with emphasis on more complex surfaces including the interpretation of the results from the "adjacent frequency" lunar radar experiment.

C. Surface Scattering Measurements

The radar scattering measurements of "lunar like" surfaces would be continued. Emphasis would be placed on the measurement of a wider variety of surfaces, particularly those with an easily calculated cross-section. Polarization properties would be measured according to the systematic procedures developed under the theoretical studies. It is planned to incorporate the "adjacent frequency" technique into the present system in order to establish the relationships between the surface structure and the frequency separation for more realistic surfaces. It is hoped that from the results of the lunar radar experiments, it may be possible to construct an artificial surface with scattering characteristics similar to the radar-scattering characteristics obtained from the lunar radar system.

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